~~Description~~

METHOD FOR IDENTIFICATION OF AN OSCILLATION IN AN ELECTRICAL POWER SUPPLY SYSTEM

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CLAIM FOR PRIORITY

This application claims priority to International Application No. PCT/DE00/03434 which was filed in the German language on September 27, 2000.

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TECHNICAL FIELD OF THE INVENTION

The invention relates to a method for producing at least one signal (oscillation signal), which indicates an oscillation in an electrical power supply system~~, in which method the phase current and the phase voltage~~

15 ~~are in each case sampled from at least one phase of the power supply system, forming phase current and phase voltage sample values, impedance values are formed from the phase current and phase voltage sample values, the impedance values are monitored for the presence of any~~

20 ~~oscillation and, if an oscillation is identified, at least one memory element is set, and the oscillation signal is output at its output, after setting the memory element, further impedance values are checked to determine whether the oscillation that has been found~~

25 ~~is still continuing, the memory element remains uninfluenced if the oscillation continues, and the memory element is reset if the oscillation has stopped.~~

BACKGROUND OF THE INVENTION

30 ~~A method such as this is described in~~ German Laid-Open Specification DE 195 03 626 A1 describes a method of identifying an oscillation. In this method, once a memory element has been set, further impedance values are checked to determine whether the oscillation that

35 has been found is still continuing, by determining the rate of change of the magnitude of respectively successive impedance values ~~and, if~~. If it is found that the rate of change is above a limit value, this identifies that the oscillation has stopped, and the

memory element is reset. It ~~has been found to be~~ is difficult to define such a limit value, particularly when a large number of generators are connected in the power supply networks, and complex oscillations can thus occur.

SUMMARY OF THE INVENTION

The invention relates to a method for producing at least one signal (oscillation signal), which indicates an oscillation in an electrical power supply system, in which method the phase current and the phase voltage are in each case sampled from at least one phase of the power supply system, forming phase current and phase voltage sample values, impedance values are formed from the phase current and phase voltage sample values, the impedance values are monitored for the presence of any oscillation and, if an oscillation is identified, at least one memory element is set, and the oscillation signal is output at its output, after setting the memory element, further impedance values are checked to determine whether the oscillation that has been found is still continuing, the memory element remains uninfluenced if the oscillation continues, and the memory element is reset if the oscillation has stopped.

The invention ~~is based on the object of specifying~~ specifies a method of detecting ~~by means of which~~ the oscillation behavior of an electrical power supply system ~~can be detected safely and reliably at all times~~ in a safe and reliable manner.

~~For a method of the type mentioned initially, this object is achieved according to~~ In one embodiment of the invention, there is a method ~~in~~ that ~~the~~ checks ~~of~~ the ~~further~~ impedance values and makes use of an oscillation model which is formed from previous impedance values associated with the oscillation, or from variables which are dependent on these impedance ~~values;~~ a values. A check is then carried out to

determine whether a further impedance value formed at that time or a variable which is dependent on ~~this~~the further impedance value differs from the oscillation model, and any occurrence of a further impedance value

5   or of a variable dependent on this impedance value which differs from the oscillation model is assessed as the oscillation having stopped.

~~One major~~ One advantage of the method according to the
10   invention is that the oscillation model allows even complex oscillations to be described, and it is thus possible to identify that the oscillation has stopped with a high level of reliability even in the case of such complex oscillations.

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The oscillation model can advantageously be determined by means of a least squares estimation method. This estimation method allows a mathematical oscillation model to be produced from successive
20   impedance values which have been formed after the setting of the memory element, that is to say after the start of the oscillation.

A function in the form $f(x) = ax^3 + bx^2 + cx + d$ with the
25   parameters a, b, c and d can be used as the model rule for ~~this~~the oscillation model, in which one or more parameters can be defined to be zero before the start of the estimation method. First, second or third order power functions can ~~thus~~ be used as the model rule.
30   Furthermore, a sum of sine and cosine functions, which decay with time, can be used as the model rule for the oscillation model. These model rules make it possible to describe even complex oscillations mathematically.

35   The oscillation model can be formed directly for the determined impedance values of the oscillation, or else for variables dependent on these impedance values. Resistance values R, reactance values X, time derivative values dZ/dt of the impedance, time

derivative values dR/dt of a resistance or time
derivative values dX/dt of a reactance can be used as
dependent variables. Choice of the most suitable
variable for the oscillation model makes it possible to
5   determine with a high level of reliability that the
oscillation has stopped, with the choice of the
variable being dependent on the individual system
configuration of the electrical power supply system.

10   _____In one advantageous embodiment of the invention,
positive phase sequence system impedance values can be
formed from the phase current and phase voltage sample
values, and a common memory element can be provided,
and a common oscillation signal can be produced, for~~all~~
15   the phases in the power supply system. This variant can
be used when the aim is to make a statement relating to
any oscillation occurring at the same time in all the
phases in the power supply system.

20   _____In a further~~advantageous~~ embodiment of the method
according to the invention, phase impedance values are
formed from the phase current and phase voltage sample
values of each phase of the power supply system to be
investigated for oscillation, and a dedicated memory
25   element is provided, and a dedicated oscillation signal
is produced, for each of these phases. In this
embodiment, the oscillation response of each individual
phase in the power supply system can be investigated
~~separately, that is to say~~separately. That is, both
30   the starting and the stopping of an oscillation are
identified. This is particularly advantageous when
oscillations occur in~~only~~ a single phase, but not in
all the phases, in the power supply system.
Oscillations such as these frequently occur in the case
35   of so-called single-pole pauses in high-voltage
systems. Single-pole pauses are produced by single-pole
conductor ground faults, which can be expected
frequently in high-voltage systems, and in which an arc
is struck between one conductor and ground. In this

type of fault, a single-pole pause is~~produced that is to say~~produced. That is, the single phase in which the single-pole conductor-ground fault has occurred is switched off briefly. The arc is thus quenched, and the fault is frequently corrected. Switching off a single pole of one phase can result in oscillations occurring in the remaining phases which are not switched off. These oscillations cannot be identified, for example, by monitoring the positive phase sequence system impedance values, since positive phase sequence system impedance values ~~can be~~are formed~~only~~ when sample values are available for~~all~~ the phases in the power supply system. In the case of a single-pole pause, it is~~now highly~~ advantageous to be able to produce a dedicated oscillation signal for each phase in the power supply ~~system; during~~system. During the single-pole pause, this oscillation signal is produced~~only~~ for those phases which are not switched off. The oscillation behavior of the power supply system can thus be determined individually for each phase, and independently of the state of the other phases.

_____The phase impedance values of the individual phases in the electrical power supply system can, for example, be formed by, in order to form the phase impedance values,

- a variable U_re ~~containing~~including the real part of the phase voltage sample values, a variable U_im ~~containing~~including the imaginary part of the phase voltage sample values, a variable I_re ~~containing~~including the real part of the phase current sample values and a variable I_im ~~containing~~including the imaginary part of the phase current sample values being formed from the phase current and phase voltage sample values (i, u) for each phase,
- a phase real power variable P being determined from $P = U\_re \cdot I\_re - U\_im \cdot I\_im$,
- a phase wattless component variable Q being determined from $Q = U\_im \cdot I\_re + U\_im \cdot I\_re$,

- a squared phase current amplitude variable I^2 being determined from $I^2 = I\_re \cdot I\_re + I\_im \cdot I\_im$,
- system-frequency components in each case being removed by means of least squares estimation method from the phase real power variable P, from the phase wattless component variable Q and from the squared phase current amplitude variable I^2, and
- phase resistance values R being determined from $R=P/I^2$ and phase reactance values X being determined from $X=Q/I^2$, and phase impedance values $Z=R+jX$ being thus determined.

When forming the phase impedance values, it is~~particularly~~ advantageous to remove the system frequency components (for example 50 Hz components) from the phase real power variable P, from the phase wattless component variable Q and from the squared phase current amplitude variable I^2 by means a least squares estimation method in each case. Such system frequency interference components would adversely affect the evaluation of the phase impedance values determined from these variables.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to explain the invention further, Figure 1 shows a block diagram of an exemplary embodiment of the method according to the <u>invention.</u> ~~invention, Figure 2~~ <u>Figure 2</u> shows a block diagram for determining the phase impedance ~~values,~~ <u>values.</u>

Figure 3 shows the impulse response of the filters used for impedance ~~determination,~~<u>determination.</u>

Figure 4 shows the real power and wattless component variable profiles before ~~filtering,~~ ~~and~~<u>filtering.</u>

Figure 5 shows the real power and wattless

component variable profiles after filtering.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows, schematically, a method for
5   determining the oscillation behavior of a three-phase
electrical power supply system, by means of which a
dedicated oscillation signal Pd1, Pd2 and Pd3 is
produced for each phase in the power supply system.
This is done by providing three changeover switches U1,
10   U2 and U3 and three memory elements Spi, Sp2 and Sp3,
theSp3. The connecting lines between the individual
units in the layout are designed with three poles. The
phase current and phase voltage sample values i and u
of all three phases are supplied to a unit for
15   impedance determination Ib, at whose output phase
impedance values Z are output for the three phases.
These phase impedance values Z are supplied via the
changeover switches U1, U2 and U3 to an oscillation
identification unit Pe. The oscillation identification
20   unit Pe uses the time profiles of the phase impedance
values Z to identify the occurrence of any oscillation
in the individual phases, for example in phase 1, and
emits an oscillation set signal Ps at its output for
each phase in which oscillation is identified, for
25   example for the phase 1. The oscillation set signal Ps
sets the memory element associated with the respective
phase, for example Sp1, and this memory element emits
at its output the phase-specific oscillation signal,
for example, Pd1. When an oscillation signal is being
30   emitted, for example the oscillation signal Pd1, the
changeover switch, for example U1, associated with the
respective phase is switched over. The phase impedance
values Z which are still formed for the phase in which
the oscillation has been identified, for example the
35   phase 1, are supplied to an oscillation signal
resetting unit Pü. This oscillation signal resetting
unit Pü identifies that the oscillation has stopped
and, in this case, emits an oscillation reset signal Pr
at its output, which resets the memory element for the

respective phase, for example Sp1. The oscillation
signal for the respective phase, for example Pd1, is
thus also no longer emitted, and the respective
changeover switch, for example U1, moves back to its
5   original position once again. In response to a
stimulus, a unit for phase selection Pa ensures that
the phase impedance values of the phases to be
investigated for oscillation are in each case processed
by the oscillation identification unit Pe and by the
10   oscillation signal resetting unit Pü.

The method of operation of the four units
comprising impedance determination Ib, the oscillation
identification unit Pe, the oscillation signal
15   resetting unit Pü and phase selection Pa will be
explained in more detail in the following text.

As shown in Figure 2, the phase current and phase
voltage sample values i and u are filtered in the
20   impedance determination unit Ib by means of orthogonal
FIR filters F1, F2, F3 and F4, thus resulting in the
production of a variable U_re containing the real part
of the phase voltage sample values, a variable U_im
containing the imaginary part of the phase voltage
25   sample values, a variable I_re containing the real part
of the phase current sample values, and the variable
I_im containing the imaginary part of the phase current
sample values.

30   Figure 3 shows the impulse responses of the
filters F1 to F4, with the impulse response of the
filters F1 and F3 which determine the real parts being
annotated "o", and the impulse response of the filters
F2 and F4 which determine the imaginary parts, being
35   annotated "+".

As shown in Figure 2, following this, a phase real
power variable P is calculated in accordance with
equation (1) below and a phase wattless component

variable Q is calculated in accordance with equation (2) in the unit 5, and a squared phase current amplitude variable I^2 is calculated in accordance with equation (3) in the unit 6.

$$P = U\_re \cdot I\_re - U\_im \cdot I\_um \qquad (1)$$
$$Q = U\_im \cdot I\_re + U\_im \cdot I\_re \qquad (2)$$
$$I^2 = I\_re \cdot I\_re + I\_im \cdot I\_im \qquad (3)$$

After this, the phase real power variable P, the phase wattless component variable Q and the squared phase current amplitude variable I^2 are filtered in units 7 and 8 in order to remove the interference 50 Hz components contained in these variables; this results in the filtered variables P', Q' and $I^{2'}$. The least squares estimation method used for this filtering will be explained in detail further below.

The upper illustration a) in Figure 4 shows the profile of the real power variable P, and the lower illustration b) shows the profile of the Wattless component variable Q, before filtering by means of the least squares estimation method, in each case plotted against the time t.

The upper illustration a) in Figure 5 shows the profile of the real power variable P', and the lower illustration b) shows the profile of the Wattless component variable Q', after filtering by means of the least squares estimation ~~method; it~~method. It can clearly be seen that the 50 Hz components have been removed.

As shown in Figure 2, after the filtering in the unit 9, phase resistance values R and phase reactance values X are determined in accordance with equation (4), and the phase impedance values Z=R+jX determined from them are emitted at the output of the impedance determination unit Ib.

$$R = P'/I^2{}' \qquad X = Q'/I^2{}' \qquad\qquad (4)$$

_____A least squares estimation method using a signal model in accordance with equation (5) is applied separately to each of the variables P, Q and I^2 in order to filter out the 50 Hz components ~~contained~~included in the phase real power variable P, in the phase Wattless component variable Q and in the squared phase current amplitude variable I^2.

$$y_k = A \cdot e^{-\frac{t}{\tau}} \cdot \sin(\omega_0 k \cdot T_A) + B \cdot e^{-\frac{t}{\tau}} \cdot \cos(\omega_0 k \cdot T_A) + C \qquad\qquad \textbf{(5)}$$

_____The estimation method uses the squared phase current amplitude variable I^2, the phase real power variable P and the phase Wattless component variable Q to calculate the parameters A, B and C in the signal model. The parameter C gives the sought magnitude of the phase real power variable P', of the phase Wattless component variable Q' and of the squared phase current amplitude variable $I^2{}'$. The summands with the parameters A and B model the 50 Hz components. The variable ωo is the frequency (50 Hz) to be filtered out, and T_A is the sampling time.

_____If an equivalent circuit with~~only~~ two generator machines at the ends of a power transmission line is considered for the power supply system, the amplitude of the 50 Hz components decays with the time constants τ of the sum impedance between the two generator machines in accordance with equation (6), where L is the loop inductance and R is the loop resistance of the circuit which is closed via the two generator machines.

$$\tau = \frac{\sum L}{\sum R} \qquad\qquad \textbf{(6)}$$

_____The coefficients A, B and C are determined such that the sum of the squares of the errors between values y determined from the phase current and phase voltage sample values i and u and the sample values yk

5   calculated in accordance with equation (5) becomes a minimum (see equation (7)).

$$J = \sum_{i=k-N}^{k}\left(y_i - h(\underline{\Theta}_k)\right)^2 \rightarrow \text{MIN} \tag{7}$$

10   _____In equation (7), J represents the Q-criterion to be minimized. The signal model included in equation (5) is used as the function $h(\underline{\Theta}_k)$. The parameters A, B and C to be determined form a vector $\underline{\Theta}_k$ in accordance with equation (8).

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$$\underline{\Theta}_k = \begin{pmatrix} A \\ B \\ C \end{pmatrix} \tag{8}$$

_____The Q-criterion J is derived based on the parameter vector $\underline{\Theta}_k$ in order to solve the minimization

20   task. For the signal model in accordance with equation (5), this then results in equation (9) together with equation (10).

$$0 = \sum_{i=k-N}^{k} 2\underline{\gamma}_i^T\left(y_i - \underline{\gamma}_i\underline{\Theta}_k\right) \tag{9}$$

$$\underline{\gamma}_i^k = \frac{\partial h}{\partial \Theta_k} \qquad \underline{\gamma}_i^k = \begin{pmatrix} \sin\left(\frac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} \\ \cos\left(\frac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} \\ 1 \end{pmatrix} \tag{10}$$

_____If equation (9) is solved for the vector $\underline{\Theta}_k$, then this results in equation (11), by means of which, and using the matrix $\underline{S}_k$ included in equations (12) and (13), the vector $\underline{\Theta}_k$ is determined.

5

$$\underline{\Theta}_k = \underline{S}_k^{-1} \sum_{i=1}^{k} \underline{\gamma}_i^T y_i \qquad \text{(11)}$$

$$\underline{S}_k = \sum_{i=k-N}^{k} \underline{\gamma}_i^T \underline{\gamma}_i \qquad \text{(12)}$$

$$\underline{S}_k = \begin{pmatrix} \sin^2\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} & \sin\left(\dfrac{2\pi}{T}iT_A\right)\cos\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} & \sin\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} \\ \cos\left(\dfrac{2\pi}{T}iT_A\right)\sin\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} & \cos^2\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} & \cos\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} \\ \sin\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} & \cos\left(\dfrac{2\pi}{T}iT_A\right)\cdot e^{-\frac{iT_A}{\tau}} & 1 \end{pmatrix}$$

$$\text{(13)}$$

_____Of the parameters A, B and C ~~contained~~included in the vector $\underline{\Theta}_k$, only the parameter C is evaluated. The
10 vectors $\underline{\gamma}_i^k$ in accordance with equation (10) and the matrix $\underline{S}_k$ in accordance with equation (13) are calculated and are stored as constants, so that they are available ~~every time~~when the method is used.

15 _____Monotony criteria are applied to the locus curves of the impedance values in the impedance plane in the oscillation identification unit Pe, in order to identify the oscillation process. This method for identification of the oscillation process is~~known per
20 se, and is~~ described in German Patent DE 197 46 719 C1.

_____The oscillation signal resetting unit Pü determines whether an oscillation which has already been identified is still continuing. The procedure used
25 for this purpose comprises the production of an oscillation model for phase impedance values Z associated with the oscillation. A check is then carried out to determine whether the locus curve which is described by the newly determined phase impedance

values Z still corresponds to the oscillation model. When producing the oscillation model, it is assumed that the locus curve is free of discontinuities, and that its direction changes~~only very~~ slowly. In the present exemplary embodiment, the locus curve is described by a first order power function, that is to say by a linear equation, in accordance with equation (14).

$$X(R) = m \cdot R + X_0 \tag{14}$$

The parameters m and X0 are determined by means of a non-recursive least squares estimation method from the last N determined phase impedance values Z.

The linear equation is used as a model rule for the least squares estimation method, with the parameter m characterizing the gradient, and the parameter XO characterizing the offset of the linear equation. The parameters m and XO for the model in accordance with equation (14) are determined from the last determined value pairs (Ri, Xi) of the phase impedance values Zi such that the sum of the squares of the errors between the values Xi determined from the measured phase current and phase voltage sample values i and u and the values X calculated in accordance with equation (14) is a minimum (see equation (15)).

$$J = \sum_{i=k-N}^{k} (X_i - h(\underline{\Theta}_k))^2 \rightarrow MIN \tag{15}$$

In equation (15), J is the Q-criterion to be minimized, the model rule in accordance with equation (14) is used as the function $h(\underline{\Theta}_k)$. In accordance with equation (16), the parameter vector $\underline{\Theta}_k$ contains the parameters m and XO, to be determined, from the model rule.

$$\underline{\Theta}_t = \begin{pmatrix} m \\ X_0 \end{pmatrix} \tag{16}$$

In order to solve the minimization task, the Q-criterion J ~~must be~~is derived on the basis of the parameter vector Θ_k. The following equations (17) and (18) are then obtained for the signal model in accordance with equation (14):

$$0 = \sum_{i=k-N}^{k} 2\underline{\gamma}_i^T \left(X_i - h(\underline{\Theta}_k)_i \right) \tag{17}$$

$$\underline{\gamma}_i^k = \frac{\partial h}{\partial \Theta_k} = \begin{pmatrix} R \\ 1 \end{pmatrix} \tag{18}$$

If equation (17) is solved for the parameter vector Θ_k, then this results in equation (19) for determining the parameter vector Θ_k.

$$\underline{\Theta}_k = \underline{S}_k^{-1} \sum_{i=1}^{k} \underline{\gamma}_i^T y_i \tag{19}$$

where

$$\underline{S}_k = \sum_{i=k-N}^{k} \underline{\gamma}_i^T \underline{\gamma}_i \tag{20}$$

$$\underline{S}_k = \sum_{i=k-N}^{k} \begin{pmatrix} R_i^2 & R_i \\ R_i & 1 \end{pmatrix} \tag{21}$$

After substitution of the parameters in equation (14), this~~thus~~ results in the estimated oscillation model. If a newly determined phase impedance value Z corresponds to the oscillation ~~model, that is to say~~model. That is, it is within a tolerance band around the linear equation represented by equation (14), then this identifies that the oscillation is continuing. If the newly determined phase impedance value Z is outside the tolerance band, then this identifies that the oscillation has stopped, and an oscillation reset signal Pr is emitted at the output of

the oscillation signal resetting unit Pü for the memory element Sp1, Sp2 or Sp3 for the respective phase.

The phase selection unit Pa receives a stimulus from, for example, a distance protection device which is not illustrated. Depending on the nature of the stimulated loop, it determines the phases for which the oscillation identification unit Pe and/or the oscillation signal resetting unit Pü should investigate the oscillation behavior. The following table shows the association between the stimulated loops and the phases.

Stimulated loops	Phases to be investigated for oscillation behavior
L1E	L1
L2E	L2
L3E	L3
L12	L1 and L2
L23	L2 and L3
L31	L1 and L3